Selecting Thermal Designs TFAWS 2015

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8/4/2015

CASE STUDIES

COSMIC BACKGROUND EXPLORER (COBE):

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LOW DENSITY SUPERSONIC DECELERATOR (LDSD)SUPERSONIC FLIGHT DYNAMICS TEST (SFDT):

AJ MASTROPIETRO JPL

Getting Started on a Design…. What do you do?

Keep the design as simple as possible

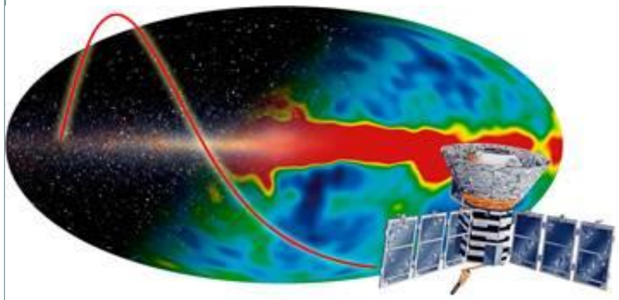
- Does a design that only uses radiators, isolators, conductive material, blankets, control coatings, and heater power work? *Simple, reliable, least expensive*
- Do you need more complex or non-standard design?
  - Heat pipes
  - Thermoelectric coolers
  - Cryocoolers
  - Dewars
  - Phase change materials
  - OSRs
  - Gimbal system
  - Louvers
  - Heat Switches

Getting Started With The Thermal Design

- Thermal Requirements (Operational, Survival, Test, and Ground Operations)
  - Temperature
  - Stability
  - Gradients
- Modes of Operation
- Component thermal power dissipations
- Orbit
- Class of Hardware (redundancy and reliability)
- Spacecraft Orientation (operational and safe-hold)
- Resources (heater power, mass, schedule and budget)
- Component location and S/C physical size and shape*

* Engineer iterates to determine these parameters.

Question of the day: ***Is it the thermal engineer's responsibility to develop a design that meets all the requirements given to him/her by the project?***



COBE
Spacecraft and Instruments

THERMAL DESIGN CASE STUDY

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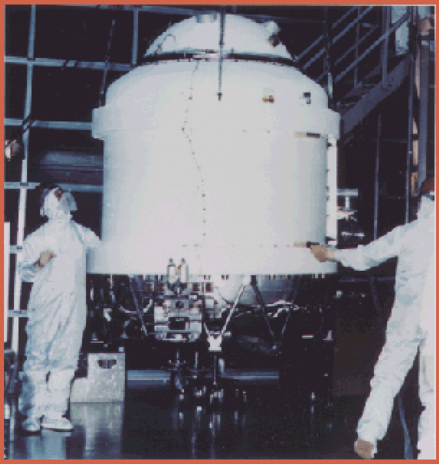


Scope of Presentation

This presentation is part of a lecture series describing the thermal design of various NASA missions. It describes how the thermal design evolved from the requirements and challenges.

Specifically this presentation provides top-level information on the thermal design of the COBE spacecraft and instruments. It includes

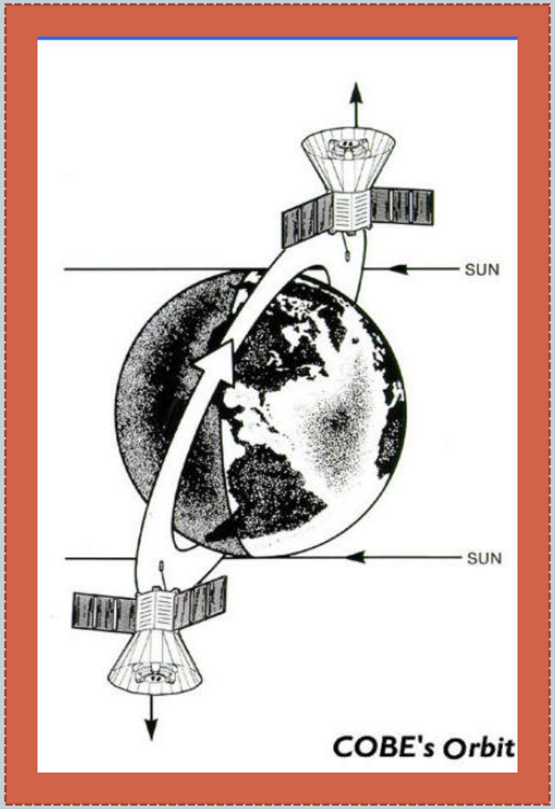
- General Information About The Mission
- Orbit
- Thermal Requirements and Resulting Design
- Challenges

Overview

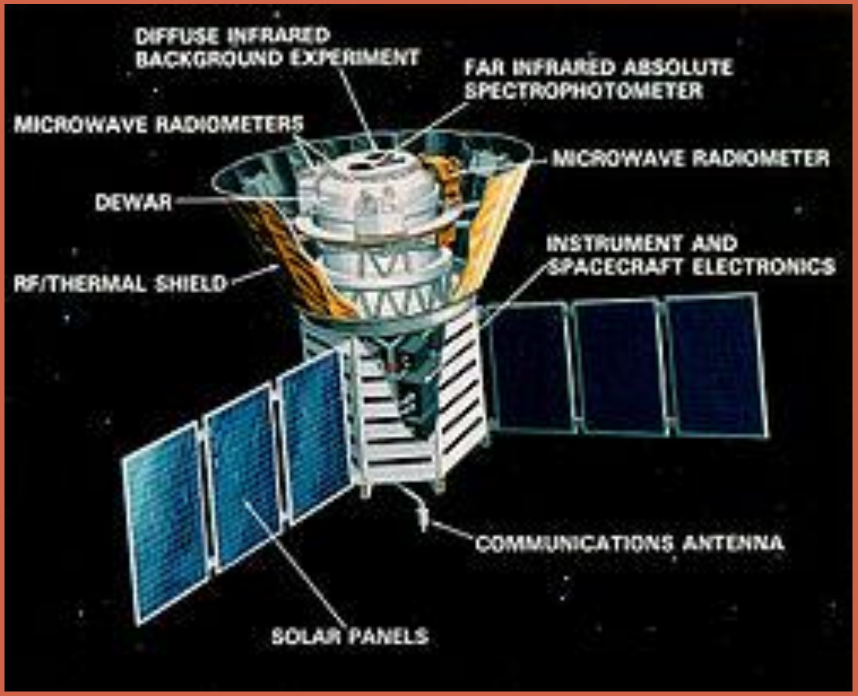
- Cosmic Background Explorer (COBE)
- Launched 11/18/1989 from California
- Investigated the cosmic background radiation and provided evidence that supported the Big Bang theory of the universe
- Dr. John Mather (GSFC Scientist) received the Nobel prize in Physics
- The spacecraft was originally designed to be deployed from the Space Shuttle. Redesigned to be launched on a Delta after the Challenger accident.
- It took 6 months to get one full sky map; it was the goal to have the cryogen in the liquid helium dewar last for 1 year in order to get two full sky maps.

Orbit and Orientation

- Sun Synchronous, Polar Orbit, Inclination 99°
- Spinning at 0.8 RPM
- The orbit nearly passes over the Earth's poles at an altitude of **900 km (559 miles)**
- This orbit was selected since it precesses (turns) to follow the apparent motion of the Sun relative to the Earth. Therefore the spin axis stays pointed almost perpendicular to the direction of the Sun and in a generally outward direction from the Earth. From a science perspective it allowed the full sky to be mapped. From a thermal perspective the cryogenic instruments could be shielded from the sun's and earth's heat.



COBE Overview



COBE spacecraft Thermal PDL (Product Design Lead): Rob Chalmers

- Helium Dewar
- Instruments
  - FIRAS (inside Helium Dewar)
  - DIRBE (inside Helium Dewar)
  - DMR (Exterior of Dewar)
- Deployables
  - Solar Arrays (3 wings : 9 panels)
  - Earth/Sun Shield
  - Antenna
  - Dewar Cover (Ejected)
- Structure
  - Hexagonal bus
  - Supported Dewar and shield from top deck
  - Electronic boxes mounted to inside surface of radiators

COBE Spacecraft
Requirement Versus Thermal Design Implementation

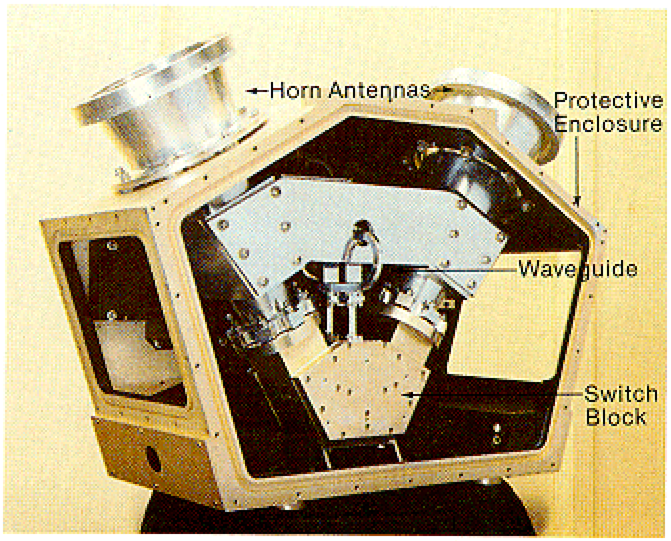
Requirement	Design Implementation
• One year lifetime of Dewar to perform two maps of the sky (mainshell <150 K)	• Titanium isolators from deck Dewar to minimize parasitic heat, white coating (S13GLO) to maximize heat transfer to space, sun/earth shield to protect instrument from environment
• Keep electronics within thermal limits	• Radiators with Black (MS94B) / white(MS74*) strip patterns; cold biased with operational and survival heaters with thermostats
• Science viewing required slow spin so all bays had the same thermal environment.	• All sides of spacecraft received sun and components with similar thermal requirements were mounted together and the strip patterns were tailored for bays.
• Minimize thermal back-loading on FIRAS external calibrator	• Silver Teflon on exterior of sun/earth shield and highly specular interior to reflect energy to space.

*MS74 was selected due to absorptivity stability

Thermal Challenges
Redesign of Shuttle to Delta Launch Vehicle

- Mass! To achieve the 900 Km orbit COBE had to go on a serious diet. 1.5 lbs = 1 km. A lower orbit would have meant more Earth influence on the instruments. The deletion of the propulsion system was the biggest mass saving; however the design of every electronics box, harness, and structure was reviewed and in many cases changed.
- Packaging – Smaller fairing meant deployable solar arrays, Sun/Earth shield and antenna. The three DMRs went from being mounted on stands to being mounted on the Dewar.
- DMR was almost deleted from the COBE instrument suite because of these constraints.

DMR - Differential Microwave Radiometers



The 9.6 mm DMR receiver partially assembled. Corrugated cones are antennas.

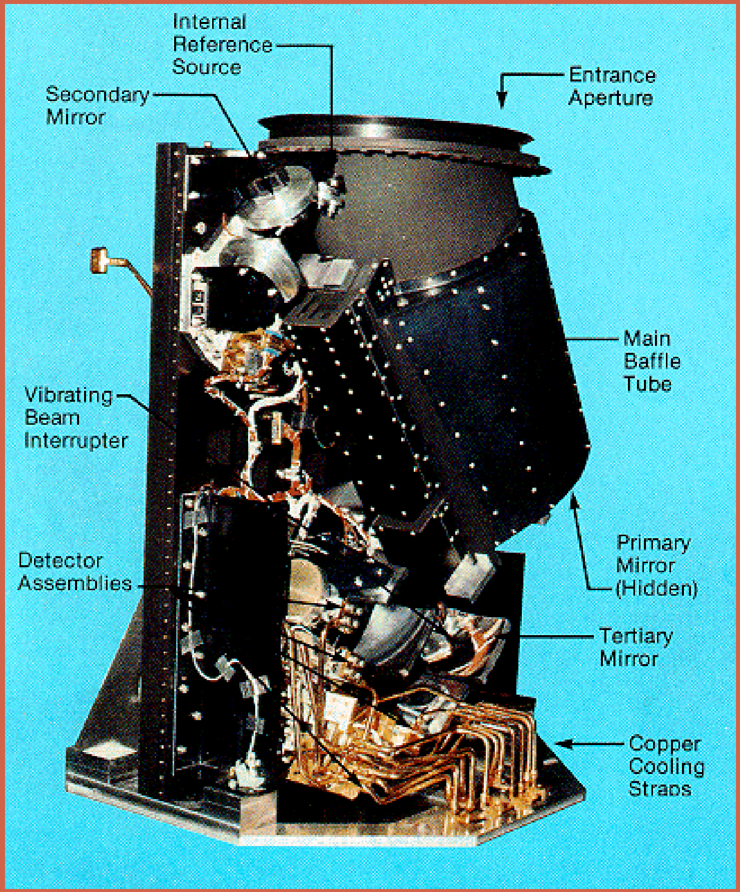
DMR Thermal PDL: Frank Kirchman

Three DMRs External to Dewar

Requirement	Thermal Implementation
53 and 90 GHz Cold Heads < 150 K	•White Control Coating •Isolation Mounted (titanium) •Survival heater (A/B)
51 GHz Critical region and warm box ~25°C	•Small radiator •MLI blanket •Operational Heater (A/B) •Isolation from cold areas

DIRBE –Diffuse Infrared Background Experiment Inside Super fluid Liquid Helium Dewar

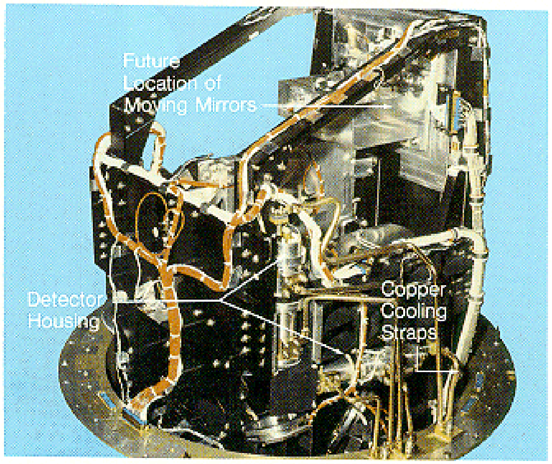
Pointed "off spin axis" – instrument observes half the sky every orbit.



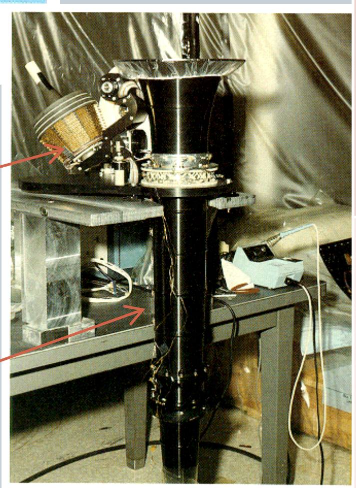
Requirement	Thermal Implementation
Detectors < 3.5 K	•Heat sunk to Dewar bottom interface ring with 99.999% copper rods •G10 washers for isolation
Survive Cooldown	•Black coating on structure to minimize gradients. •Material selection (CTE) /thickness
Internal Reference Source (IRS) transient temperature profile 3.5 – 20 K	•heat sunk to I/f at top of dewar with a copper rod. Transient power effects did not effect stability of detectors

DIRBE Thermal PDL: Carol Mosier

FIRAS –Far Infrared Absolute Spectrophotometer Inside Super fluid Liquid Helium Dewar



Test unit being prepared for vibration test. Horn, calibrator, and mirror mechanism are not shown.



Horn antenna with movable calibrator. Protective plastic covers will be removed.

Requirement	Thermal Implementation
Bolometers < 1.5 K	•Heat sunk to Dewar bottom interface ring with copper rods with flexible section for vibration - dedicated location away from DIRBE detector heat sinking. •G10 washers for isolation
Survive cooldown	•Same Philosophy as DIRBE instrument
Internal/External reference horns, Internal Calibrator 5 – 20 K	•Kapton Film Heaters •G10 Isolators to minimize heater power and parasitic heat into dewar •Ical material/design similar to Ext Cal
External Calibrator •< Temp of Space •Command to 20 K •Swings in/out of ext. reference horn •Black •Minimal gradients	•Heat sunk to top of dewar (away from stable bolometers) •Kapton Film Heaters •Flexible heat strap •Eccosorb material •copper spreaders internally

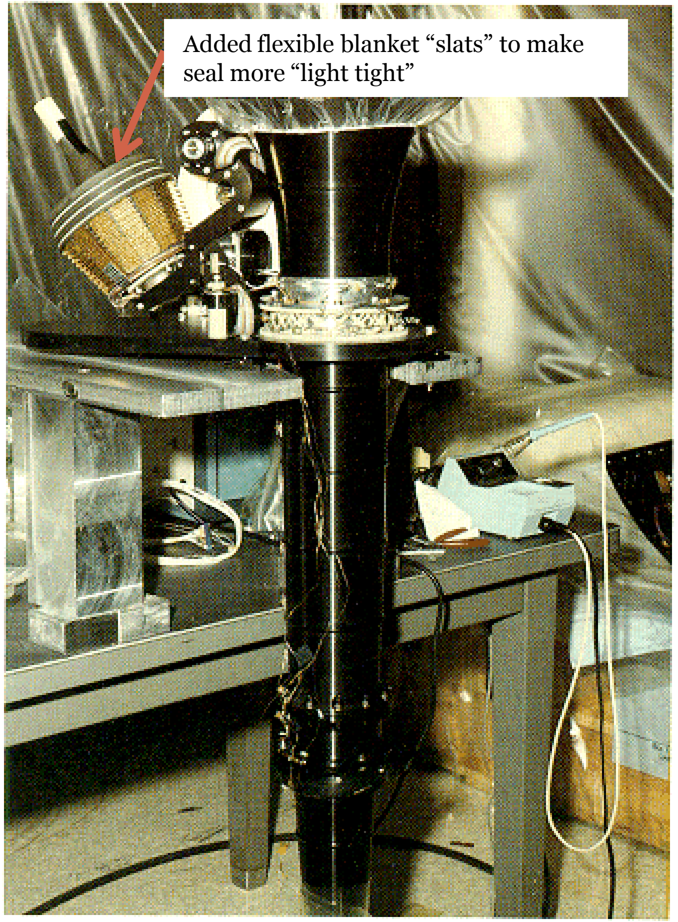
FIRAS Thermal PDL: Carol Mosier

Thermal Challenges
Cryogenic Design of FIRAS/DIRBE

- Today we have a wealth of information on how to design and implement cryogenic instruments. However back on COBE there wasn't much available. Test programs to determine thermal parameters were done. Here's a few examples:
  - Conductivity/specific heat of materials at low temperatures
  - Interface materials (indium, gold foil)
  - Coatings thermal/optical properties and adhesion
  - Mounting/calibration of heaters and sensors
- Thermally induced stresses were not understood. Several components in developmental models broke during cooldown. There were also concerns that optic performance would change at cryogenic temperatures. Therefore a new way of analyzing the problem evolved → STOP analysis. Temperatures had to be hand mapped onto structural models; in turn stresses were hand mapped onto optical models.
- There were also some surprises for example:
  - DIRBE chopper utilized magnetic fields to open and close tines. The eddy current dissipation caused the tines to heat – redesign used wires to conduct heat to base.
  - Vibration of copper rods lowered thermal conductivity.

The External Calibrator – Thermal Challenge

- A few months prior to COBE's delivery to the launch site it was discovered that the external calibrator did not remain seated within the horn when horizontal.
- It was discovered that the stiffness of the cabling/heat straps at <3 K was the cause.
- The design that was mechanically acceptable reduced the thermal conduction path to the helium dewar.
- The calibrator was external to the dewar when it was positioned in the horn and therefore received thermal backloading from the shield/DMRs/Dewar.
- **The external calibrator needed to be colder than space for COBE to work!**



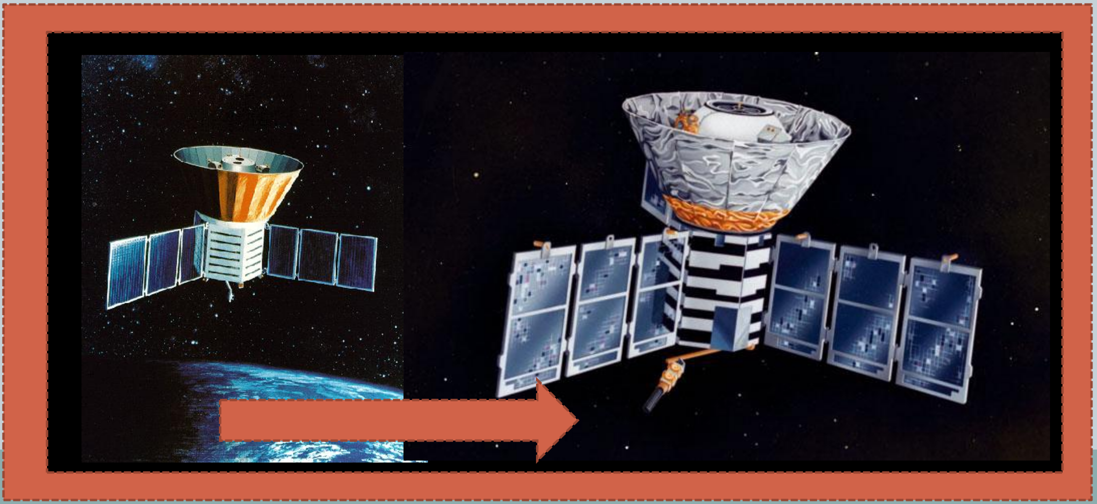
Horn antenna with movable calibrator. Protective plastic covers will be removed.

The External Calibrator – Thermal Challenge

(continued)

- The less conductive heat strap caused a redesign of the sun/earth shield. The interior was made more specular and the exterior was partially covered with silver Teflon instead of Kapton. Every available piece of silver teflon on the east coast was used.
- flexible blanket "slats" were added to make seal more light tight.
- The flight unit was shipped to Vandenberg while the changes to the external calibrator were thermally tested on the engineering model. A great thermal challenge was that specular ray-tracing techniques were not part of the standard thermal software used on COBE.

The external calibrator did get colder than space! It also performed over the full temperature range needed for calibration.



Post Launch Summary and Challenges

- Spacecraft and Instruments within temperature requirements.
- Dewar cryogen was being depleted faster than expected. Upon review of cryogenics analysis it was found that (1) Heat load due to parasitic heat from cabling and (2) Earth limb effects that would have been seen in a few months had not been accounted for. To minimize the earth limb effect the spacecraft orientation was tilted a couple of degrees toward the sun. The lifetime of the dewar was over 10 months (goal 12 months).
- More detailed thermal modeling of the FIRAS calibrators/horn was done post-launch. This aided in the understanding/post processing of the data.

- COBE provided evidence that supported the big bang theory of the universe. According to the Nobel Prize committee, "the COBE-project can also be regarded as the starting point for cosmology as a precision science". (John Mather pictured)